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Challenges for a Railway Inspection and Repair System from Railway Infrastructure

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***Abstract*—Robots and automation techniques are used in many industries for a long period because of the economic advantages and efficiency. Though the railway has a long history compared to other transportation systems, it still lacks wide application of modern technologies such as robots and AI. Track maintenance using robotic technologies has gained some attraction from both infrastructure managers and researchers due to safety and cost benefits. A Railway Inspection and Repair System (RIRS) has been proposed using commercially available Unmanned Ground Vehicles (UGV) and an industrial manipulator for the railway track inspection and repair tasks. The use of a specially designed trolley enables the on-track and off-track navigation capability of RIRS. The infrastructure in railway is very diversified and unique in size, shape, and remoteness compared to other industries. This research investigates the unique challenges to the operation of RIRS imposed by the railway infrastructure.**

***Keywords*—track maintenance, robot, RIRS, unmanned ground vehicle, manipulator**

I. Introduction

Railway is one of the largest modes of transportation for a long time serving and helping the civilizations to grow since the very early industrial revolution. As a mode of transportation, the railway is environment friendly as it produces less carbon-di-oxide than road or air transportation system [1]. The forecast shows that in the UK number of passengers in trains will be double while the number of freights will increase by 90% by the year 2041 compared to the year 2014 [2]. To meet the demand, it is important to reduce the downtime of railway infrastructure by ensuring an optimized inspection and repair technique. For example, Network Rail Limited, owner and infrastructure manager of railway infrastructure in the UK, has a target to improve efficiency by 17% [3]. Maintenance in the railway industry includes everything such as rolling stocks, track, stations, trackside furniture, tunnels, and bridges, etc. Only in the British railway system, the management system needs to cover over 20,000 miles of track, 30,000 bridges, 2500 stations, a multitude of geographically dispersed signalling systems, electrification, and crossing systems some of which are almost 200 years old.

IN2SMART2 is a project from European Shift2Rail program to bring intelligent digitalization and modern robotic technologies to railway. Successful completion of this project will improve the maintenance task decision and asset information management framework. As the usage of the railway is escalating, maintenance tasks are becoming more restrictive, complex, diversified, and costly. Modern problems require modern technological solutions. The necessity for improved maintenance technique with improved tools are increasing promptly.

Currently, many of the inspection and repair tasks in the railway are carried out by a human operator or track recording vehicles (TRV) with specially equipped tools and sensors or with a Railway Maintenance Vehicles (RMV). Use of TRV provides the flexibility to add more sensor technologies for railway track inspection such as canny edge detector, camera, ultrasonic sensors etc[4]. State-of-the-art track recording vehicle from Network Rail, New Measurement Train (NMT), are equipped with multiple sensors and perform inspection task in a high speed [5]. Different types of railway maintenance device have some pros and cons, which are shown in Table I. Inspection by a human is very slow, laborious and cannot provide concrete information [6]. Moreover, live track on the side and adverse weather increases the risk of injury and fatality. On the other hand, TRVs and RMVs are efficient in inspection or repair but requires human involvement and are only designed to perform a specific inspection or repair task. Due to high operating costs, it is not economically feasible to use TRV and RMV for frequent track inspection or repair tasks [7]. As the sensor technologies and computational capabilities has been improved, Robots are now capable of replacing or assisting in many 4D (Dangerous, Difficult, Dirty, and Dull) tasks [8]. Therefore, robotic maintenance systems are highly demanded by flexibly combining autonomous sensing, control, decision making, remote communication, and work execution for railway track inspection and repair.

TABLE I. Types of Maintenance Devices in Railway

Platforms	*Advantages*	*Limitations*
Inspection Trolley	Easy to transport	Lower speed, only on-track navigation
Self-propelled inspection kart	Easy to transport, multipurpose	Low battery life, only on-track navigation
TRV	High speed, multiple sensors and measurememtns	High cost, only on-track navigation
RMV	Repair task, efficient than human	High cost, only on-track navigation

There are many types of readily available robots in the market. Unmanned Ground Vehicle (UGV), Unmanned Aerial Vehicle (UAV), Delivery robots, Manipulators, and humanoid robots are some common types of robots available in the market for easy deployment. Warthog UGV from Clearpath Robotics Inc, AGEMA UGV from Milanion Group are examples of UGVs. UR series manipulators from Universal Robotics are used in many manufacturing applications. Starship delivery robots are helping companies to deliver food in the local areas [9] while vacuum robot from iRobot is helping in house cleaning [10]. All these robots are designed to perform in a specific environment with a particular infrastructure setup such as household, inside industrial buildings, or outside local communities. Railway environments are different than many industrial setups because of the infrastructures. Railway infrastructures consist of tracks, stations, trackside furniture, overhead lines, signal posts, etc. Some components of the infrastructures are small and repetitive such as sleepers, clips, fishplates, point motors, etc. while some are big such as tunnels or stations. These unique infrastructures pose some distinctive challenges for the robots. It is necessary to find these challenges before designing the command-and-control system of a railway maintenance robot.

This paper describes the importance of railway and its maintenance to derive the motivation for finding the challenges for a robot in the first section. In the later section, a proposed railway maintenance robot has been described. Later, unique challenges for the railway maintenance robot have been described briefly. In the end, a brief description to overcome these challenges has been mentioned.

II. Railway Inspection and Repair System (RIRS)

An autonomous ground vehicle, a type of wheeled robots, such as Warthog from Clearpath Robotics, can run in different types of terrain. Manipulators such as the UR10e arm which has 6 degrees of freedom from Universal Robotics have been used in many industrial applications. The proposed Railway Inspection and Repair System (RIRS), shown in Fig. 1, consists of a mobile manipulator and a trolley which will perform two tasks: inspection and repair [11], [12], [13]. The overall system weigh 450kg and has a dimension of 1400mm x 1300mm x 1800 mm. It is running on Robot Operating System (ROS) and has many sensors for perception, navigation, and task completion. Key specifications of the sensors used in the robot are given in Table II. In the inspection task, it will inspect the track while traveling with an arm head camera and detect defects and save the location of the defects for future reference. In the repair task, it will use

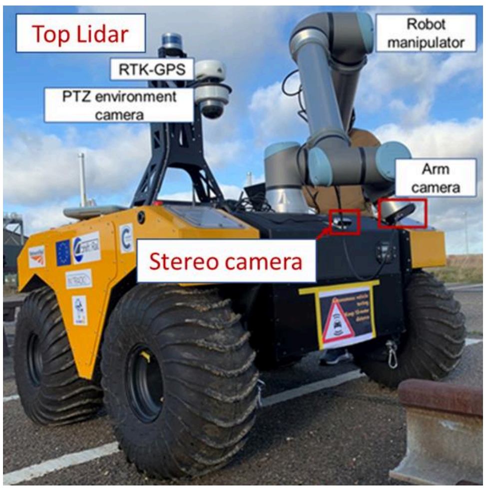

Fig. 1. Railway Inspection and Repair System (RIRS)

Fig. 2. Components of a railway track

the manipulator and gripper to perform the repair job according to defect type. In addition, the Road Rail Conversion will be implemented to fulfil both the on-track and off-track operation requirements and flexible transformation for supporting train schedules. RIRS can perform inspection and repair inside the railway track during on-track navigation while off-track navigation will help RIRS to inspect and repair trackside and adjacent areas of railway track. The RIRS system also have a wi-fi base station which creates a local wi-fi network with a range of 1km to connect between the robot and the proprietary devices and enables communication between the robot and command-and-control system.

TABLE II. Key specifications of sensors in RIRS

Sensor	Model	Key specs
IMU	Microstrain Gx5	• Pitch-roll static/dynamic accuracy ±0.25°/0.4° • sampling rate up to 1000Hz
GPS	Novatel GPS	• Real time kinematic (RTK) • Accuracy: 1com
LiDAR	Velodyne VLP-16	• 360° horizontal FOV and a 30° vertical FOV • Measurement Range: Up to 100 m
Environment camera	Axis PTZ	• HDTV 1080p and 10x optical zoom • Continuous 360° pan
Wrist camera	Robotiq Wrist camera	• Range: 70mm to infinity • Resolution: 0.2 Mpx to 5Mpx
RGB-D camera	Intel Realsense 415i	• Range: 0.2m to 20m • Depth resolution and FPS 1280x720 and 30

III. Challenges for a Railway Maintenance Robot

RIRS is a mobile manipulator designed to perform both inspection and repair tasks in the railway track. In the inspection task, it will inspect the track while traveling with an arm head camera and detect defects and save the geo-location of the defects from the Global Positioning System (GPS) data for future reference. In the repair task, it will use the manipulator and end-effector to perform the repair job according to defect type. In addition, the manual Road rail conversion with a help of an operator will be implemented to fulfil both the on-track and off-track operation requirements and flexible transformation for supporting train schedules to ensure maximum usage of the railway assets. However, due to some distinct characteristics of railway infrastructures, mobile manipulators will face some unique challenges.

A. Railway Track

Railway infrastructure consists of the track, trackside furniture, stations, platforms, switches and crossings, tunnels, bridges etc. Some of the infrastructures are small such as signal posts or trackside furniture, while some are big such as stations or platforms. Among all the infrastructure, the track is the most critical infrastructure of the railway. The railway track, shown in Fig. 2, is the path where the trains run. The main components of a traditional track are rails, sleepers, ballasts, fittings and fastenings, switches, and crossings.

Rails are parallel and continuous steel structures in a railway track. They guide the train in a lateral path and minimize the risk of derailment. Also, they bear and transmit the vertical stress and carry the trains along the designated path. Sleepers are the rectangular-shaped support element that holds the rails in the correct gage and alignments. Sleepers are positioned perpendicular to the rails. Apart from holding the rails, sleepers also provide firm and even support, transfer load from rail to wider area of ballast. Ballast is a layer of granular material to hold the sleeper in the correct position and provides a hard and levelled ground. Normally, broken stones are used as ballast material. Transferring and distributing the load from sleepers to a wider area is another functionality of ballast.

- One big difference between rail track and the conventional road is that road is plain while railway track is uneven. RIRS will face vibration from the uneven formation of the ground which is created because of railway track geometry.
- In between the rails, there are sleepers and stones which are almost flat, but the rails stand on top of sleepers. In British standard railway, rail height is 138mm. If the mobile manipulator wants to change the side, going from right to left and vice-versa for navigating in trackside from inside the track, it should cross over the rails as shown in Fig. 3. So, the RIRS should have the capability to cross an obstacle of a minimum of rail height.
- In many places, trackside area is very narrow and steep slope. Also, Before making any movement during off-track navigation in these areas, RIRS need to access the available spaces for safe movement.
- Platforms are big obstacle which the RIRS cannot overcome. The space between the platform and the adjacent track is not enough for the RIRS for off-track navigation, as shown in Fig. 4.

B. Switches and Crossings

Switch and crossing are a mechanism that guides the rolling stock in the desired direction. It is very common near the railway station and railway junction. In a simple form, it can guide trains between two railway tracks. While in a complex form, it can guide multiple trains in multiple tracks. The switching mechanism consists of stock rails, wing rails, check rails and switch rails. Among these, switch rails are movable. Wing rails relate to the switch rails. In ancient times, a manual lever mechanism was used to control the position of the switch rail. In modern days, electric motors are used for automatic control of switching. Check rails are also known as guard rails which ensure that the train is guided to the right track, shown in Fig. 5.

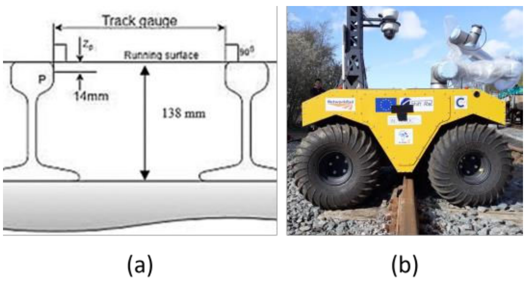

Fig. 3. Movability challenges for RIRS along the track

Fig. 4. Congested space between the track and platform

Though switch and crossings are a part of the track, they impose more complex problems for a mobile manipulator to navigate along the track.

- Standard British railway gauge, the distance between two rails is 1435mm. But in switches and crossings, the gap between two rails is reduced. This change in dimension will create a problem for RIRS to navigate in pneumatic wheels.
- For the operation of switch and crossings, a point machine, electric motors, or manual lever mechanism are installed beside the track. Additionally, in the case of countries with cold weather where snow is very common, a heating mechanism is installed to remove the snow and ice from the switch and crossings. These items will act as an obstacle for RIRS and will also reduce the accessible area for off-track navigation along the track.
- RIRS can either climb over these point machines or electric motors or bypass them if enough space is available. But these items are very delicate and ensures safety of the trains. So RIRS might damage the switch and crossings if it cross over them.

C. Tunnel

A tunnel is a confined space under a mountain, river or sea to allow continuous running of rails. It is very helpful to shorten the journey duration and bypassing mountains or waterways. Depending on the geography ad requirement, the tunnel can be very long or short.

- Autonomous RIRS requires communication with the control centre. As the tunnel has no GPS or cellular signal, lack of communication with the control centre can create a "Kidnapped Robot Problem (KRP)" [14] which may lead to catastrophic failure to localization and navigation system.
- Operating in a confined space is a challenge for RIRS. Some of the tunnels have very limited space around the track. Some of the tunnel has curved wall, which

Fig. 5. Basic components of a switches and crossings

might not be feasible for RIRS navigation. Confined space also create problem for manipulation. Without safe workspace, manipulator may collide with the tunnel wall or other structure which creates a safety concern for the manipulator.

D. *Overhead Line Equipment (OLE) and Trackside Furniture*

Modern railway tracks also have Overhead Line Equipment (OLE) and Signal and Telecommunication (S&T) devices running along the track on a support system consisting of trackside poles, links, or clamps. Overhead catenary electric cables transfer energy to run the train through a pantograph system while the S&T are essential for safe and speedy movement of the trains.

Trackside furniture or trackside equipment are positioned on the side of the railway track. They are important to transfer information between the train and command-and-control-centre and safety. Signals post, marker post, Location case (LOC's) etc. are example of trackside furniture. Depending on the place and requirement, the signal, or marker post size can vary. Trackside furniture provides an advantage. These can be used as a feature for autonomous navigation. Using this equipment as a reference RIRS may locate itself more precisely. But, apart from that this equipment also act as obstacle for the mobile manipulator and reduce the accessible areas along the track. For safe running of trains, a structure gauge or minimum clearance outline has been created. Key clearances are shown in Table III.

- Poles for the electric lines, signal post and other trackside furniture will act as obstacle for the RIRS.
- overhead electric lines act as a faraday cage to reduce the GPS and cellular signal strength.

TABLE III. STRUCTURE GAUGE OR MINIMUM CLEARANCE FOR RAILWAY INFRASTRUCTURE IN THE UK

Item	**Clearance**
Fixed wire (from track plane)	6100 mm
Temporary wire (from track plane)	5500 mm
High or big structures (Post, platforms, Ladders, Handrailas, screening etc.) (from running edge)	- minimum 1364 mm - normal 1624 mm
Cable route (from running edge)	- minimum 1250 mm - normal 2000 mm
Walkway (from track)	- minimum 1300 mm - normal 2000 mm
Signaling equipment (marker post, LOC etc.) (from running edge)	730 mm

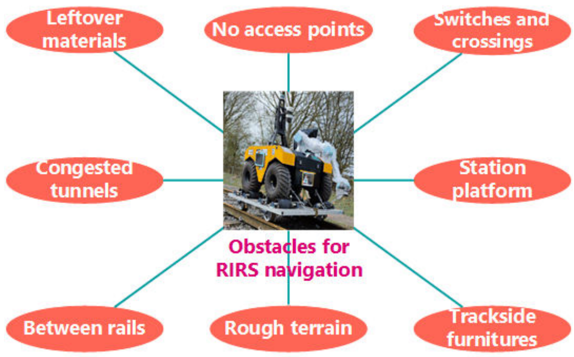

Fig. 7. Obstacles for navigation in railway track

Fig. 6. Basic components of a switches and crossings

IV. DISCUSSION

Traditional railway maintenance duties are time-consuming, dangerous, and difficult. Because of better sensing and computing capabilities, robots have a significant chance of improving railway track inspection and maintenance techniques. Railway environment is different than other industrial workspace because of unique structure and outdoor environment. As there are many structures around the track, these structures will work as an obstacle for the RIRS. Trolley is one of the stand-alone characteristics of RIRS with other robotics maintenance system which enables both off-track and on-track navigation.

RIRS faces less obstacle during on-track navigation as most of the infrastructure are out of the track. RIRS can move only forward or backward during on-track navigation. While navigating off-track, it must consider all the surrounding railway structures and their clearances. Due to these structures and congested spaces, movability of RIRS is reduced and off-track navigation becomes challenging in some instances as shown in Fig. 7. In many congested places, off-track navigation is not possible as there is not enough space for the movement of RIRS, such as old tunnels with less clearance or station platforms. As shown in Table III, the clearance between the signaling equipment and the track is 730mm which is less than the width of RIRS (1300mm). RIRS can not navigate through this clearance. For crossing this equipment, either RIRS need to use on-track navigation technique or detour the signaling equipment if enough space is available on the side for off-track navigation.

Apart from the navigational challenges from the obstacles, RIRS will also need to take care of the vibration created by the uneven surfaces during the off-track navigation. Loss of GPS or cellular signals are also needed to be considered while designing the command-and-control system for the RIRS. These signal losses can be solved by using data budgeting or local data storage facilities, local mapping technique and using perception form other sensors.

Another remarkable feature of RIRS over other railway maintenance vehicle is the road rail conversion capability which gives RIRS some advantages. With the proper design of command-and-control system, RIRS can achieve better obstacle avoidance competence. As shown in Fig. 8, RIRS can switch between the off-track and on-track navigation mode when there is not enough space to avoid the obstacle.

V. CONCLUSION

RIRS has a good potential to solve many problems in railway inspection and repair task. But the unique characteristics of the railway infrastructure poses some special challenges to the RIRS. Some of the obstacles can be avoided using conventional navigation technique of mobile robot while some obstacle avoidance requires special attention. The design of the command-and-control centre for RIRS need to consider all these challenges.

This work focuses the challenges of the RIRS from the infrastructure perspective. It is also important to discover the challenges from the workspace, safety, and task characteristics point of view. Workspace for a robot in the railway industry is quite divergent as the robot needs to work in the various outdoor scenario. Adverse weather conditions impose risk for the robot. Designing a command-and-control system and inspection and repair task framework considering all these challenges will be the next challenges.

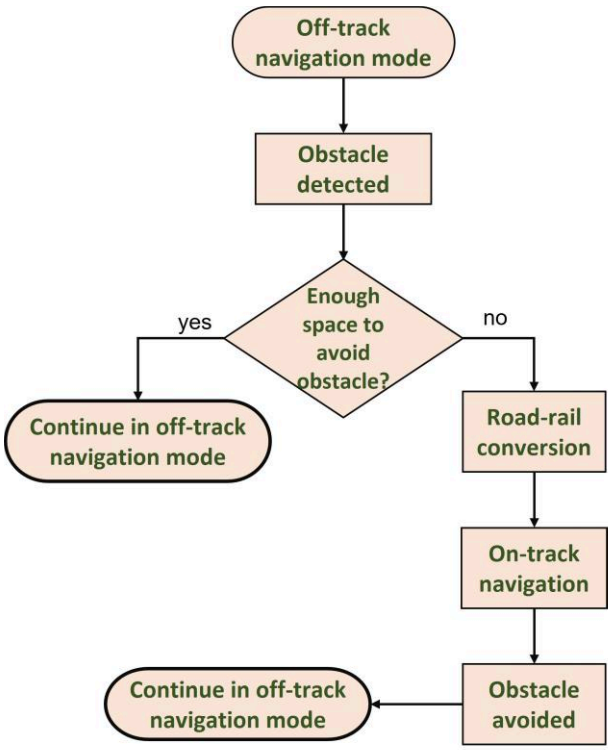

Fig. 8. Top level command-and-control flowchart for obstacle avoidance in congested place

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